WHAT IS CLAIMED IS:

CLAIMS

1. In a thermal printer including a print head element, a method comprising steps of:

(A) computing an input energy to provide to the print head element based on a current temperature of the print head element and a plurality of one-dimensional functions of a desired output density to be printed by the print head element.

2. The method of claim 1, further comprising a step of:

(B) providing the input energy to the print head element.

3. The method of claim 1, wherein the current temperature of the print head element comprises a predicted current temperature of the print head element.

4. The method of claim 3, wherein the predicted temperature is predicted based on an ambient temperature and an energy previously provided to the print head element.

5. The method of claim 3, wherein the thermal printer includes a plurality of print head elements, and wherein the predicted temperature is predicted based on an ambient temperature, an energy previously provided to the print

head element, and an energy previously provided to at least one other print head element in the plurality of print head elements.

6. The method of claim 1, wherein the plurality of one-dimensional functions comprises:

an inverse gamma function having the desired output density as an input and an uncorrected input energy as an output; and

a correction function having the current temperature of the print head element as an input and a correction factor as an output; and

wherein the step (A) comprises a step of computing the input energy by adding the correction factor to the uncorrected input energy.

7. The method of claim 6, wherein the correction function develops the correction factor by performing steps of:

developing a temperature difference value by subtracting a reference temperature from the current temperature of the print head element; and

developing the correction factor as the product of the temperature difference value and the output of a sensitivity function having the desired output density as an input and a sensitivity value as an output.

8. The method of claim 6, wherein the correction factor is positive.

9. The method of claim 6, wherein the correction

factor is negative.

10. The method of claim 1, wherein the input energy is represented by the variable E, and wherein the step (A) comprises a step of computing the input energy using an equation of the following form:

$$E = \Gamma^{-1}(d) + S(d)\left(T_a - T_\Gamma(d)\right),$$

wherein $\Gamma^{-1}(d)$ relates the desired output density d to an uncorrected input energy E_Γ, T_a is the current temperature of the print head element, $T_\Gamma(d)$ relates the desired output density d to a reference temperature, which is the temperature of the print head element when $\Gamma()$ was measured, and $S(d)$ is the slope of the temperature dependence of $\Gamma^{-1}(d)$.

11. The method of claim 1, wherein the input energy is represented by the variable E, and wherein the step (A) comprises a step of computing the input energy using an equation of the following form:

$$E = G(d) + S(d)T_a,$$

wherein $G(d)$ relates the desired output density d to an uncorrected input energy E_Γ, T_a is the current temperature of the print head element, and $S(d)$ is the slope of the temperature dependence of $G(d)$.

12. The method of claim 1, wherein the step (A) is performed within a single print head cycle of the thermal printer.

13. A thermal printer comprising:

a print head element; and

means for computing an input energy to provide to the print head element based on a current temperature of the print head element and a plurality of one-dimensional functions of a desired output density to be printed by the print head element.

14. The thermal printer of claim 13, further comprising:

means for providing the input energy to the print head element.

15. The thermal printer of claim 13, wherein the current temperature of the print head element comprises a predicted current temperature of the print head element.

16. The thermal printer of claim 15, wherein the predicted temperature is predicted based on an ambient temperature and an energy previously provided to the print head element.

17. The thermal printer of claim 15, wherein the print head element is one of a plurality of print head elements, and wherein the thermal printer further comprises means for predicting the predicted temperature based on an ambient temperature, an energy previously provided to the print head element, and an energy previously provided to at least one other print head element in the plurality of print head elements.

18. The thermal printer of claim 13, wherein the means for computing the input energy comprises:

inverse gamma function means having the desired output density as an input and an uncorrected input energy as an output;

correction function means having the current temperature of the print head element as an input and a correction factor as an output; and

means for computing the input energy by adding the correction factor to the uncorrected input energy.

19. The thermal printer of claim 18, wherein the correction function means comprises:

means for developing a temperature difference value by subtracting a reference temperature from the current temperature of the print head element; and

means for developing the correction factor as the product of the temperature difference value and the output of a sensitivity function having the desired output density as an input and a sensitivity value as an output.

20. The thermal printer of claim 13, wherein the input energy is represented by the variable E, and wherein the means for computing the input energy comprises means for computing the input energy using an equation of the following form:

$$E = \Gamma^{-1}(d) + S(d)\left(T_a - T_\Gamma(d)\right),$$

wherein $\Gamma^{-1}(d)$ relates the desired output density d to an uncorrected input energy E_Γ, T_a is the current temperature of the print head element, $T_\Gamma(d)$ relates the desired output density d to a reference temperature, which is the temperature of the print head element when $\Gamma()$ was measured, and $S(d)$ is the slope of the temperature dependence of $\Gamma^{-1}(d)$.

21. The thermal printer of claim 13, wherein the input energy is represented by the variable E, and wherein the means for computing the input energy comprises means for computing the input energy using an equation of the following form:

$$E = G(d) + S(d)T_a,$$

wherein $G(d)$ relates the desired output density d to an uncorrected input energy E_{Γ}, T_a is the current temperature of the print head element, and $S(d)$ is the slope of the temperature dependence of $G(d)$.

22. The thermal printer of claim 13, wherein the means for computing the input energy comprises means for computing the input energy within a single print head cycle of the thermal printer.

23. An apparatus for producing a plurality of input energies to provide to a plurality of print head elements in a thermal print head to produce a printed image corresponding to a source image having a distribution of desired densities, the apparatus comprising:

head temperature model means for:

receiving as inputs, for each of a plurality of print head cycles: (1) an ambient temperature, and (2) a plurality of input energies provided to the plurality of print head elements during at least one previous print head cycle; and for

producing as an output, for each of the plurality of print head cycles, a plurality of predicted temperatures of the plurality of print head elements at the beginning of the print head cycle, wherein the plurality of predicted temperatures are developed using a first recursive process utilizing a multi-resolution heat propagation model; and

inverse media density model means for:

receiving as inputs, for each of the plurality of print head cycles: (1) the plurality of predicted temperatures, and (2) a subset of the distribution of desired densities that is to be printed during the print head cycle; and for

producing as an output, for each of the plurality of print head cycles, a plurality of input energies to be provided to the plurality of print head elements during the print head cycle.

24. The apparatus of claim 23, wherein the inverse media density model means comprises:

inverse gamma function means for receiving the subset of the distribution of desired densities as an input and producing a plurality of uncorrected input energies as an output;

sensitivity function means for receiving the subset of the distribution of desired densities as an input and producing a plurality of sensitivity values as an output;

reference temperature function means for receiving the subset of the distribution of desired densities as an input and producing a plurality of reference temperatures as an output;

a subtractor for subtracting the plurality of reference temperatures from the plurality of predicted temperatures to produce a plurality of temperature differences;

a multiplier for multiplying the plurality of sensitivity values by the plurality of temperature differences to produce a plurality of correction factors; and

an adder for adding the plurality of correction factors to the plurality of uncorrected input energies to produce the plurality of input energies.

25. The apparatus of claim 23, wherein the head temperature model means further receives as an input at least one previous predicted temperature produced by the head temperature model.

26. In a thermal printer having a print head including a plurality of print head elements, a method for developing, for each of a plurality of print head cycles, a plurality of input energies to be provided to the plurality of print head elements during the print head cycle to produce a plurality of output densities, the method comprising steps of:

(A) using a multi-resolution heat propagation model to develop, for each of the plurality of print head cycles, a plurality of predicted temperatures of the plurality of print head elements at the beginning of the print head cycle; and

(B) using an inverse media model to develop the plurality of input energies based on the plurality of predicted temperatures and a plurality of densities to be output by the plurality of print head elements during the print head cycle.

27. The method of claim 26, wherein the step (A) comprises a step of developing the plurality of predicted temperatures based on an ambient temperature and a plurality of input energies provided to the plurality of print head elements during at least one previous print head cycle.

28. The method of claim 26, wherein the step (A) comprises a step of developing the plurality of predicted temperatures based on a plurality of previous predicted temperatures for the plurality of print head elements.

29. The method of claim 26, wherein the step (A) comprises a step of developing, for each of the plurality of print head elements, a predicted temperature based on a predicted temperature of at least one of the other print head elements at the beginning of at least one previous print head cycle.

30. The method of claim 26, further comprising a step of:

(C) defining a three-dimensional grid having an *i* axis, an *n* axis, and a *j* axis, wherein the three-dimensional grid comprises a plurality of resolutions, wherein each of the plurality of resolutions defines a plane having a distinct coordinate on the *i* axis, wherein each of the plurality of resolutions comprises a distinct two-dimensional grid of reference points, and wherein any one of the reference points in the three-dimensional grid may be uniquely referenced by its *i*, *n*, and *j* coordinates;

wherein associated with each of the reference points in the three-dimensional grid is an absolute temperature value and an energy value;

wherein the absolute temperature value associated with a reference point having coordinates $(0,n,j)$ corresponds to a predicted temperature of a print head element at location j at the beginning of time interval n, and wherein the energy value associated with the reference point having coordinates $(0,n,j)$ corresponds to an amount of input energy to provide to the print head element at location j during time interval n; and wherein the step (B) comprises a step of:

(B)(1) developing the plurality of input energies by developing energy values associated with a plurality of reference points having an i coordinate of zero based on the plurality of output densities and the absolute temperature values associated with the plurality of reference points having an i coordinate of zero.

31. The method of claim 30, further comprising steps of:

(D) calculating relative temperature values using the following equations:

$$T^{(i)}(n,j) = T^{(i)}(n-1,j)\alpha_i + A_i E^{(i)}(n-1,j)\text{; and}$$

$$T^{(i)}(n,j) = (1-2k_i)T^{(i)}(n,j) + k_i\left(T^{(i)}(n,j-1) + T^{(i)}(n,j+1)\right)$$

in which $T^{(i)}(n,j)$ refers to a relative temperature value associated with a reference point having coordinates (i,n,j);

(E) calculating absolute temperature values using the following recursive equation:

$$T_a^{(i)}(*,*) = I_{(i+1)}^{(i)} T_a^{(i+1)}(*,*) + T^{(i)}(*,*) ,$$

for i = *nresolutions* - 1, *nresolutions* - 2,…, 0;

with initial conditions specified by:

$$T_a^{(nresolutions)}(n,*) = T_S(n) ,$$

wherein *nresolutions* is the number of resolutions in the three-dimensional grid, T_S is an ambient temperature, $T_a^{(i)}(n,j)$ refers to an absolute temperature value associated with a reference point having coordinates (i,n,j), and $I_{(i+1)}^{(i)}$ is an interpolation operator from resolution $i+1$ to resolution i; and wherein the step (B)(1) comprises a step of:

calculating the plurality of input energies using the following recursive equation:

$$E^{(i)}(n,j) = I_{(i-1)}^{(i)} E^{(i-1)}(n,j) ,$$ for i = 1, 2, …, *nresolutions* - 1;

with initial conditions specified by

$$E^{(0)}(n,j) = G(d(n,j)) + S(d(n,j))T_a^{(0)}(n,j)$$

wherein $G(d(n,j))$ relates the desired output density d to an uncorrected input energy E_Γ, $T_a^{(0)}(n,j)$ is an absolute temperature value associated with a reference point having coordinates (0,n,j), and $S(d(n,j))$ is a the slope of the temperature dependence of $G(d(n,j))$.

32. The method of claim 31, further comprising a step of providing the plurality of input energies $E^{(0)}(n,j)$ to the plurality of print head elements during each time interval n.

33. The method of claim 26, wherein the steps (A) and (B) are performed during a single print head cycle of the thermal printer.

34. A thermal printer comprising:

a print head including a plurality of print head elements; and

means for developing, for each of a plurality of print head cycles, a plurality of input energies to be provided to the plurality of print head elements during the print head cycle to produce a plurality of output densities, the means for developing the plurality of input energies comprising:

first means for using a multi-resolution heat propagation model to develop, for each of the plurality of print head cycles, a plurality of predicted temperatures of the plurality of print head elements at the beginning of the print head cycle; and

second means for using an inverse media model to develop the plurality of input energies based on the plurality of predicted temperatures and a plurality of densities to be output by the plurality of print head elements during the print head cycle.

35. The thermal printer of claim 34, wherein the first means comprises means for developing the plurality of predicted temperatures based on an ambient temperature and a plurality of input energies provided to the plurality of print head elements during at least one previous print head cycle.

36. The thermal printer of claim 34, wherein the first means comprises means for developing the plurality of predicted temperatures based on a plurality of previous predicted temperatures for the plurality of print head elements.

37. The thermal printer of claim 34, wherein the first means comprises means for developing, for each of the plurality of print head elements, a predicted temperature based on a predicted temperature of at least one of the other print head elements at the beginning of at least one previous print head cycle.

38. The thermal printer of claim 34, further comprising:

means for defining a three-dimensional grid having an i axis, an n axis, and a j axis, wherein the three-dimensional grid comprises a plurality of resolutions, wherein each of the plurality of resolutions defines a plane having a distinct coordinate on the i axis, wherein each of the plurality of resolutions comprises a distinct two-dimensional grid of reference points, and wherein any one of the reference points in the three-dimensional grid may be uniquely referenced by its i, n, and j coordinates;

wherein associated with each of the reference points in the three-dimensional grid is an absolute temperature value and an energy value;

wherein the absolute temperature value associated with a reference point having coordinates $(0,n,j)$ corresponds to a predicted temperature of a print head element at location j at the beginning of time interval n,

and wherein the energy value associated with the reference point having coordinates $(0,n,j)$ corresponds to an amount of input energy to provide to the print head element at location j during time interval n; and wherein the second means comprises:

means for developing the plurality of input energies by developing energy values associated with a plurality of reference points having an i coordinate of zero based on the plurality of output densities and the absolute temperature values associated with the plurality of reference points having an i coordinate of zero.

39. The thermal printer of claim 38, further comprising:

means for calculating relative temperature values using the following equations:

$$T^{(i)}(n,j) = T^{(i)}(n-1,j)\alpha_i + A_i E^{(i)}(n-1,j)\text{ ; and}$$

$$T^{(i)}(n,j) = (1-2k_i)T^{(i)}(n,j) + k_i\left(T^{(i)}(n,j-1) + T^{(i)}(n,j+1)\right)$$

in which $T^{(i)}(n,j)$ refers to a relative temperature value associated with a reference point having coordinates (i,n,j);

means for calculating absolute temperature values using the following recursive equation:

$$T_a^{(i)}(*,*) = I_{(i+1)}^{(i)} T_a^{(i+1)}(*,*) + T^{(i)}(*,*)\ ,$$

for $i = nresolutions - 1,\ nresolutions - 2, \ldots,\ 0$; with initial conditions specified by:

$$T_a^{(nresolutions)}(n,*) = T_S(n)\ ,$$

wherein *nresolutions* is the number of resolutions in the three-dimensional grid, T_S is an ambient temperature,

$T_a^{(i)}(n,j)$ refers to an absolute temperature value associated with a reference point having coordinates (i,n,j), and $I_{(i+1)}^{(i)}$ is an interpolation operator from resolution i+1 to resolution i; and wherein the second means comprises:

means for calculating the plurality of input energies using the following recursive equation:

$$E^{(i)}(n,j) = I_{(i-1)}^{(i)} E^{(i-1)}(n,j), \text{ for } i = 1, 2, \ldots, nresolutions - 1;$$

with initial conditions specified by

$$E^{(0)}(n,j) = G(d(n,j)) + S(d(n,j))T_a^{(0)}(n,j)$$

wherein $G(d(n,j))$ relates the desired output density d to an uncorrected input energy E_Γ, $T_a^{(0)}(n,j)$ is an absolute temperature value associated with a reference point having coordinates (0,n,j), and $S(d(n,j))$ is the slope of the temperature dependence of $G(d(n,j))$.

40. The thermal printer of claim 39, further comprising means for providing the plurality of input energies $E^{(0)}(n,j)$ to the plurality of print head elements during each time interval n.

41. A method for developing an input energy to provide to a print head element in a print head of a thermal printer to produce output having a desired density, the method comprising steps of:

(A) developing an uncorrected energy using a first function that has the desired density as an input and the uncorrected energy as an output;

(B) developing a correction factor using a correction function that has the desired density and a temperature of the print head element as inputs and the correction factor as an output; and

(C) modifying the uncorrected energy using the correction factor to produce the input energy.

42. The method of claim 41, wherein the step (C) comprises a step of adding the correction factor to the uncorrected energy.

43. The method of claim 41, wherein the temperature of the print head element comprises a predicted temperature of the print head element.

44. The method of claim 41, wherein the step (B) comprises steps of:

(B)(1) developing a sensitivity value using a sensitivity function that has the desired density as an input and the sensitivity value as an output; and

(B)(2) multiplying the sensitivity value by the temperature of the print head element to produce the correction factor.

45. The method of claim 41, wherein the step (B) comprises steps of:

(B)(1) developing a sensitivity value using a sensitivity function that has the desired density as an input and the sensitivity value as an output;

(B)(2) developing a temperature difference value by subtracting a reference temperature from a temperature of the print head element; and

(B)(3) multiplying the sensitivity value by the temperature difference value to produce the correction factor.

46. The method of claim 45, wherein the first function comprises an inverse of a gamma function, wherein the gamma function takes as an input an energy and produces as an output a density produced by the print head element when provided with the energy, wherein a reference temperature function takes as an input a density and produces as an output a temperature of the print head element when the print head element produced the density during measurement of the gamma function, and wherein the step (B)(2) comprises steps of:

developing a reference temperature value as the output of the reference temperature function with the desired density as the input; and

developing the temperature difference value by subtracting the reference temperature value from a temperature of the print head element.

47. The method of claim 41, wherein the steps (A), (B), and (C) are performed during a single print head

cycle of the thermal printer.

48. A thermal printer comprising:

a print head including a print head element; and

means for developing an input energy to provide to the print head element in a print head of a thermal printer to produce output having a desired density, the means for developing the input energy comprising:

means for developing an uncorrected energy using a first function that has the desired density as an input and the uncorrected energy as an output;

means for developing a correction factor using a correction function that has the desired density and a temperature of the print head element as inputs and the correction factor as an output; and

means for modifying the uncorrected energy using the correction factor to produce the input energy.

49. The thermal printer of claim 48, wherein the means for modifying the uncorrected energy comprises means for adding the correction factor to the uncorrected energy.

50. The thermal printer of claim 48, wherein the temperature of the print head element comprises a predicted temperature of the print head element.

51. The thermal printer of claim 48, wherein the means for developing the correction factor comprises:

means for developing a sensitivity value using a sensitivity function that has the desired density as an input and the sensitivity value as an output; and

means for multiplying the sensitivity value by the temperature of the print head element to produce the correction factor.

52. The thermal printer of claim 48, wherein the means for developing the correction factor comprises:

means for developing a sensitivity value using a sensitivity function that has the desired density as an input and the sensitivity value as an output;

means for developing a temperature difference value by subtracting a reference temperature from a temperature of the print head element; and

means for multiplying the sensitivity value by the temperature difference value to produce the correction factor.

53. The thermal printer of claim 52, wherein the first function comprises an inverse of a gamma function, wherein the gamma function takes as an input an energy and produces as an output a density produced by the print head element when provided with the energy, wherein a reference temperature function takes as an input a density and produces as an output a temperature of the print head element when the print head element produced the density during measurement of the gamma function, and wherein the means for developing the temperature difference value comprises:

means for developing the reference temperature value as the output of the reference temperature function with the desired density as the input; and

means for developing the temperature difference value by subtracting the reference temperature value from a temperature of the print head element.

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